GERMAN
ATV-DVWK-RULES AND STANDARDS

ADVISORY LEAFLET
ATV-DVWK-M 368E

Biological Stabilisation of Sewage Sludge

April 2003

Sponsored by the
German Federal Environmental Foundation
DBU
Deutsche Bundesstiftung Umwelt

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The German Association for Water, Wastewater and Waste, DWA (former ATV-DVWK), is the spokesman in Germany for all universal questions on water and is involved intensely with the development of reliable and sustainable water management. As politically and economically independent organisation it operates specifically in the areas of water management, wastewater, waste and soil protection.

In Europe the DWA is the association in this field with the greatest number of members and, due to its specialist competence it holds a special position with regard to standardisation, professional training and information of the public. The ca. 14,000 members represent the experts and executive personnel from municipalities, universities, engineer offices, authorities and businesses.

The emphasis of its activities is on the elaboration and updating of a common set of technical rules and standards and with collaboration with the creation of technical standard specifications at the national and international levels. To this belong not only the technical-scientific subjects but also economical and legal demands of environmental protection and protection of bodies of waters.

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DWA German Association for
Water, Wastewater and Waste
Theodor-Heuss-Allee 17
D-53773 Hennef, Germany
Tel.: +49 2242 872-333
Fax: +49 2242 872-100
E-Mail: kundenzentrum@dwa.de
Internet: www.dwa.de

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Richard Brown, Wachtberg

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Foreword

The stabilisation of sewage sludge is the most important basic operation of the overall treatment of sewage sludge. The biological processes of sewage sludge stabilisation have become widespread across the world. For decades they have been dimensioned and operated according to empirical approaches.

As usually several process objectives are to be met with the establishment and operation of sewage sludge stabilisation steps it appears, despite the diverse research work, not to be appropriate to establish plants for the stabilisation of sewage sludge solely according to microbiological and reaction kinetic approaches to dimensioning.

Current efforts towards the reduction of the stabilisation volume and of the stabilisation times, to reduce the required investment costs, as well as the combined use of municipal digestion reactors for simultaneous waste processing (e.g. co-fermentation) are to be examined critically.

The ATV-DVWK Specialist Committee AK-2 and its Working Group AK-2.1 have elaborated this Advisory Leaflet from the aspect of the current status of technology, the relevant legislation and the necessary operational requirements. With this a practice-related orientation aid is to be provided.

Authors

This Advisory Leaflet has been elaborated on behalf of and with the collaboration of the ATV-DVWK Specialist Committee AK-2 “Stabilisation, Disinfection, Conditioning, Thickening and Dewatering of Sludge” by their Working Group AK-2.1 “Stabilisation of Sludge”.

Members of Working Group AK-2.1:

EVERS, Peter	Dr.-Ing., Essen
GLASENAPP, Joachim	Dr.-Ing., Hamburg
KASSNER, Wolfram	Dipl.-Ing., Waiblingen
LOLL, Ulrich	Dr.-Ing., Darmstadt (Chairman)

Members of Specialist Committee AK-2:

BISCHOF, Fredy	Dr.-Ing., Essen
BLEI, Peter	Dipl.-Ing., Ludwigshafen
DENKERT, Ralf	Dr.-Ing., Bochum
EVERS, Peter	Dr.-Ing., Essen
GLASENAPP, Joachim	Dr.-Ing., Hamburg
HRUSCHKA, Herbert	Dr.-Ing., München
KASSNER, Wolfram	Dipl.-Ing., Waiblingen
KOPP, Julia	Dr.-Ing., Lengede
LOLL, Ulrich	Dr.-Ing., Darmstadt (Chairman)
MELSA, Armin	Prof. Dipl.-Ing., Viersen (Vice-Chairman)
WOLF, Siegfried	Dipl.-Ing., Vohburg

Guests:

ESCH, Bernd	Dipl.-Ing., Troisdorf
REIFENSTUHL, Reinhard	Dipl.-Ing., Köln

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User Notes

This Advisory Leaflet is the result of honorary, technical-scientific/economic collaboration which has been achieved in accordance with the principles applicable therefore (statutes, rules of procedure of the ATV-DVWK and the Standard ATV-DVWK-A 400). For this, according to precedents, there exists an actual presumption that it is textually and technically correct.

The application of this Advisory Leaflet is open to everyone. However, an obligation for application can arise from legal or administrative regulations, a contract or other legal reason.

This Advisory Leaflet is an important, however, not the sole source of information for correct solutions. With its application no one avoids responsibility for his own action or for the correct application in specific cases; this applies in particular for the correct handling of the margins described in the Advisory leaflet.

Abbreviations

[Translator's note: While the main terms remain unchanged as they are recognised internationally, the indices used reflect the English translation of the individual German parameter. For simplicity and clarity these have been chosen to match as far as possible the German indices. Where this is not possible the original German symbol is placed in square brackets after the English version. This procedure is not intended to create new symbols for the English-speaking engineering community but serves solely to make German symbols/indices comprehensible to non-German speakers].

Symbol		Unit	Designation
English	German		
β		mol FM/mol P	Stoichiometric overdosing
C_x		mg/l	Oxygen concentration in the aeration tank
Δ		-	Difference
ΔNO_3-N		g/(I·d) [g/(E·d)]	NO_3-N load to be differentiated
αOC		kg/h	Oxygen transfer capacity of an aerator facility in activated sludge with C_x= 0, T= 20 °C, p= 1013hPa
ΔP_{Bio-P}		g/(I·d) [g/(E·d)]	P-load biologically removed (or to be removed)
ΔSS	[ΔAFS]	g/(I·d) [g/(E·d)]	Removal of suspended solids
SS	[AFS]	kg/m³	Suspended solids
SS_{PST}	[AFS_{VK}]	kg/m³	Suspended solids in the primary settling stage
SS_{IN}	[AFS_{ZU}]	kg/m³	Suspended solids in the influent
AT	[BB]	-	Aeration tank
B_{DS}	[B_{TS}]	kg/(kg·d)	Sludge loading
BOD_5	[BSB_5]	mg/l	Biochemical oxygen demand in 5 days
COD	[CSB]	mg/l	Chemical oxygen demand
COD_{RAW}	[CSB_{ROH}]	mg/l	Chemical oxygen demand in raw sludge
D		m	Diameter
I	[*E*]	-	Inhabitant
PT	[*EW*]	E	Total number of inhabitants and population equivalents
F		-	Load
FF		-	Flocculation filtration
FA	[FHM]	-	Flocculation aid

Symbol		Unit	Designation
English	German		
PREC	[FM]	-	Precipitant
DS	[FS]	-	Digested sludge
$F\text{-}DR_{Bio\text{-}P}$	[$F\text{-}TR_{Bio\text{-}P}$]	kg/I·d [kg/E·d]	Inhabitant-related waste sludge yield from increased biological P-removal
$F\text{-}DR_{PS}$	[$F\text{-}TR_{PS}$]	kg/I·d [kg/E·d]	Primary sludge load – dry residue
IgnL	[GV]	%	Ignition loss
H		M	Height of sludge level
SVI	[*ISV*]	l/kg	Sludge volume index
N_R		W/m³	Power density for aeration and thorough mixing
O_B		kg O_2/kg BOD_5	OC/load
OC		kg O_2/(m³d)	Required aeration capacity
oDR	[*oTR*]	%	Organic part of the dry reside
OV		g O_2/(kg·oDR·d)	Respiration activity
p		hPa	Gas pressure
P_{tot}	[P_{ges}]	g/m³	Total phosphorus load
PS		g/I d [g/(E·d)]	Specific primary sludge yield
$P_{x,PS}$		%	P_{tot} content in primary sludge
$P_{x,WS}$	[$P_{x,ÜS}$]	%	P_{tot} content in waste sludge
Q_A	[Q_L]	m³/h	Air supply
T		°C	Temperature
t_R	[t_A]	d	Retention time
$t_{R,PST}$	[$t_{A,VK}$]	h	Retention time in the primary settling (tank)
DR	[*TR*]	%	Dry residue
$DR_{BIO\text{-}P}$	[$TR_{BIO\text{-}P}$]	%	Dry residue, sludge after biological phosphorus removal
$DR_{DEN,ECS}$	[$TR_{DEN,ECQ}$]	%	Dry residue, sludge after denitrification by means of external carbon sources
DR_{PREC}	[$TR_{FÄLL}$]	%	Dry residue, sludge after chemical precipitation
DR_{PS}	[TR_{PS}]	%	Dry residue, primary sludge
SS	[*TS*]	kg/m³	Concentration of suspended solids
SS_{AT}	[TS_{BB}]	kg/m³	Concentration of suspended solids in the aeration tank
SS_{ESST}	[TS_E]	kg/m³	Concentration of suspended solids in the effluent of the secondary settling tank
t_{SS}	[t_{TS}]	d	Sludge age
WS	[*ÜS*]	kg/d	Waste sludge yield
WS_{Bio}	[$ÜS_B$]	kg/d	Biological waste sludge yield
WS_{BioF}	[$ÜS_{BF}$]	kg/d	Waste sludge yield from biofilm process
WS_{BioP}	[$ÜS_{BIO\text{-}P}$]	kg/d	Waste sludge yield as a result of biological phosphorus removal
$WS_{DEN,ECS}$	[$ÜS_{DEN,ECQ}$]	kg/d	Waste sludge yield through denitrification with external carbon source (ECS = external C-source)
WS_{FF}	[$ÜS_{FF}$]	kg/d	Precipitation sludge yield from flocculation filtration
WS_P	[$ÜS_P$]	kg/d	Waste sludge yield as a result of chemical phosphorus removal (precipitation sludge)
SP	[*SF*]	-	1) Simultaneous precipitation, 2) Safety factor
ΔSP	[ΔSF]	-	Efficiency of simultaneous precipitation
V_R		m³	Reactor volume
PST	[VK]	-	Primary settling (tank)
AS	[*WS*]	-	Polymer active substance

1 Area of Application and Process Objectives of the Stabilisation

The most important process objectives of sludge stabilisation are:

- as main objective
  a) the stabilisation of the substrate
- as secondary objectives
  b) the reduction of sludge/solid matter quantities,
  c) the improvement of the dewatering ability of the sludge,
  d) the reduction of pathogens,
  e) the extraction of biogas (with anaerobic stabilisation only),
  f) the creation of buffer and storage space for sludge treatment

Process objectives b) to e) are directly related to the stabilisation and are thus dependent on this. The creation of buffer and storage space for the process chain of the overall sludge treatment is a special criterion, which has a direct effect on dimensioning of the plant.

Basically, the process objectives of stabilisation and thus the degree of stabilisation are to be aimed at the respective utilisation or disposal of the sludge.

a1) Utilisation in liquid form in farming/agriculture,
a2) Utilisation in dewatered form in farming/agriculture,
a3) Utilisation in dried form in framing/agriculture,
b) Utilisation in dewatered form in landscaping or recultivation,
c) Intermediate storage of liquid sludge in sludge ponds,
d) Storage in dewatered form,
e) Utilisation/storage in dried form (in Germany from 01.06.2005 no longer permitted),
f) Disposal in residue landfills following incineration/gasification/chemical oxidation
g) Storage following mechanical-biological treatment

An assignment of the required degree of stabilisation for utilisation or disposal is carried out in Table 1.

In order to achieve the given objectives a series of different process techniques can be employed successfully. The most important processes and their predominant areas of application are summarised in Table 2.

Table 1: Required degrees of stabilisation assigned to utilisation or disposal objectives

Utilisation or disposal objective	Required degree of stabilisation
Utilisation in farming/agriculture in liquid form	Completely stabilised**
Utilisation in farming/agriculture as well as in landscaping and in recultivation in dewatered form	Completely stabilised** for agriculture; otherwise limited stabilisation to full stabilisation**
Intermediate storage in liquid form in sludge ponds	Limited stabilisation **
Storage in dewatered form*	Dependent on the type of sludge conditioning; limited stabilisation to complete stabilisation**
Utilisation/storage in dried form*	Limited stabilisation to complete stabilisation **
Storage following incineration or similar	Stabilisation not absolutely necessary
Storage following mechanical-biological treatment	Stabilisation not absolutely necessary

* Can still only be practised as transitional solution up to 2005 in accordance with the German Technical Directive - Municipal Waste.

** *Achieve the technical stabilisation limit*

*** *In accordance with ATV-DVWK-A 131E, ATV (2000)*

Table 2: Sludge stabilisation processes

Type of process/ function	Milieu	Phase or aggregate condition	With/without self/outside heating with/without outside energy with addition of outside materials	Process	Area of application	Remarks
Biological	Aerobic	In the liquid phase	Without effective self-heating	Long-term aeration e.g. with $B_{DS} \leq 0.05$ (kg/kg · d)	For small wastewater treatment plants	-
			With (effective) self-heating	Aerobic-thermophilic sludge stabilisation (so-called liquid composting)	Smaller to medium sized wastewater treatment plants	Concurrent disinfection
		In the dewatered phase	With (effective) self-heating	Composting (e.g. in so-called “bioreactors”)	Smaller to medium sized wastewater treatment plants	Concurrent disinfection
	Anaerobic	In the liquid phase	Without outside heating	Imhoff tank	Smaller wastewater treatment plants	With new construction no longer to be used
				Open unheated digesters	Previously smaller to medium sized wastewater treatment plants	-
			With outside heating	Independently heated digesters	Medium to large wastewater treatment plants	-
	Dual=aerobic/anaerobic or anaerobic/aerobic (usually with at least one thermophilic stage	In the liquid phase	With self-heating or outside heating	Usually combination of aerobic-thermophilic/ anaerobic-mesophilic or anaerobic-thermophilic and anaerobic-mesophilic stage reactor with heat recycling	Medium wastewater treatment plants	Concurrent disinfection
Chemical	Aerobic/anaerobic	In the liquid phase	With outside energy	Wet oxidation	Larger wastewater treatment plants	Not very common
		In the dried phase	With/without outside energy	Incineration/gasification	If possible only large wastewater treatment plants	-
Chem., preventing a short-term effective material change through strong pH-value rises	(Aerobic)	In the dewatered or liquid phase	With addition of foreign matter	So-called lime “stabilisation”	Smaller to medium sized wastewater treatment plants	Only in Scandinavia also with raw sludge

The stabilisation of sewage sludge is a central basic operation of sewage sludge treatment and will retain this significance even with modified disposal objectives and standards. With the processes summarised in Table 2, the biological process alternatives play a dominating role.

The biological processes for sludge stabilisation, which are described in detail in the following chapters, vary essentially through the type of the activated microbiological biocoenosis (aerobic/anaerobic) or through the condition of the aggregate, with which the respective process is process-technically realised (fluid/solid phase). In addition, the process variants differ through the respective process temperature.

For the practical dimensioning of stabilisation plants or their components there are different approaches for the recording of the amounts of sewage sludge to be taken into account, which is investigated in particular in Chapter 3.

2 Basic Elements

2.1 Terms

This Advisory Leaflet relates to the definition of terms in DIN 4045, EN 1085, EN 12832 and EN 12255-8. The following, particularly relevant terms are described here separately, beyond the information on standardisation:

Stabilisation

Process of sludge treatment for extensive reduction of odour-forming content substances and organic sludge solids. Desired secondary objectives are the improvement of the dewatering capability and the reduction of pathogenic agents.

Pseudo-Stabilisation

Process that a product creates, whose organic substance is not biologically degradable as long as certain conditions (e.g. pH value or dryness) are maintained. If these conditions are no longer maintained the biological degradation restarts.

Psychrophilic

Process condition for organisms which are active with temperatures below 30 °C. Processes under so-called normal temperature conditions.

Mesophilic

Process condition for organisms which are active with temperatures between 30 °C and 40 °C.

Thermophilic

Process condition for organisms which are active with temperatures between 45 °C and 80 °C, and whose temperature optimum lies between 55 °C and 65 °C. With temperatures above 70 °C the term “hyperthermophilic” or “extreme thermophilic” is applied.

The other technical terms with their associated dimensioning are described with their respective first mention. Otherwise the information on the given standard specification applies.

2.2 Biochemical Basic Operations

The biochemical basic operations of the metabolic processes of the aerobic and anaerobic mixed biocoenoses, which are relevant for the biological sludge stabilisation, are described in numerous references, for which reason only the practice-related relationships are dealt with in this Advisory Leaflet.

The ATV Handbook „Klärschlamm“ (Sewage Sludge) (ATV 1996) (not yet available in English) and the there quoted specialist literature are recommended for further reading.

2.2.1 Aerobic Processes

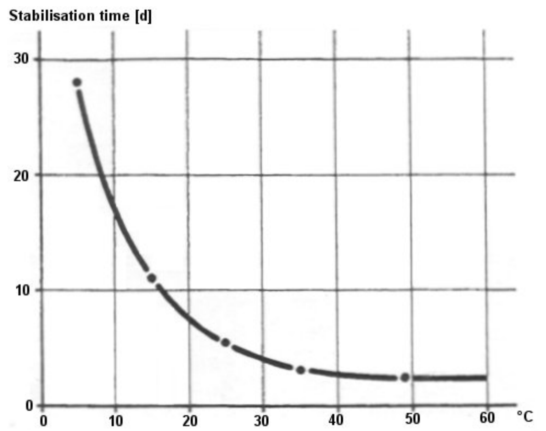
With the joint aerobic sludge stabilisation within the biological wastewater treatment stages there are numerous different micro-organisms which develop depending on the process goal and loading condition.

The sludge age influences the degree of the achievable stabilisation. The process activity is, in addition, dependent on the respective temperature level.

With separate aerobic sludge stabilisation the extent of the process activity under technical operating conditions depends very much on the temperature level in the respective reactor. With increasing reaction temperature there is there a change of the active biocoenoses from a broad organism diversity in the psychrophilic temperature range (below 30 °C) via the mesophilic (ca.

30 ºC to 40 ºC) to the thermophilic (ca. 45 ºC to 80 °C) or even hyperthermophilic (over 70 °C) range with decreasing species diversity down to monoculture.

The dependency of the required stabilisation time on the respective temperature level can be read approximately from the curve developed by LOLL (1974) and quoted in the ATV Handbook „Klär-schlamm“ (ATV 1996) (see Diag. 1).



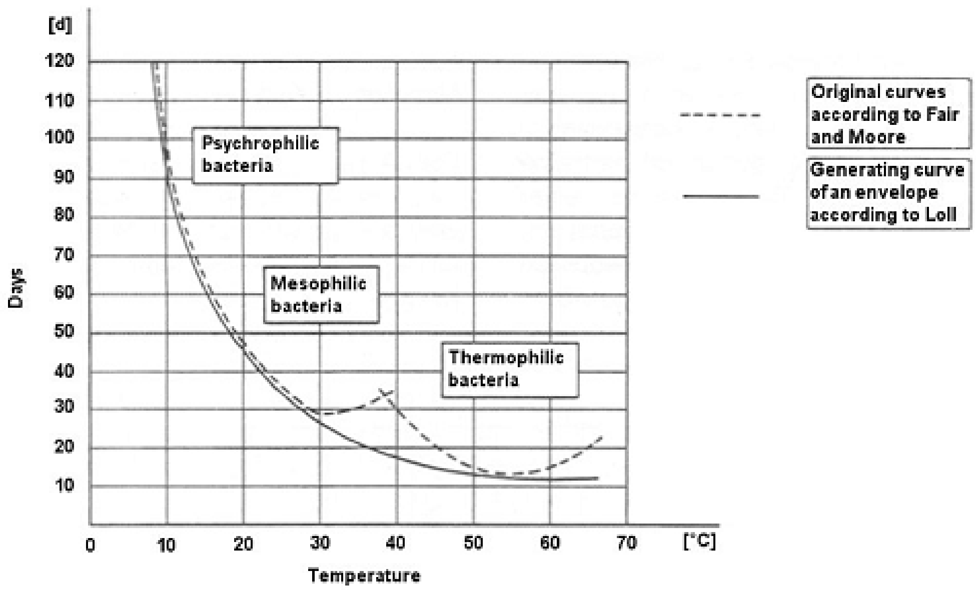
Diag. 1: Principle dependency of the aerobic stabilisation time on the temperature (ATV 1996)

2.2.2 Anaerobic Processes

The process of anaerobic degradation has, since the seventies, been described in a four-stage system using hydrolysis, acidification, acetogenic and methanogenic phase.

In the field of sewage sludge treatment a separation of the individual bacteria groups for the purpose of the separate optimisation of their respective process conditions has, up to now, not been applied successfully in practice. Due to the heterogeneous substrate characteristics it does not appear to be promising to follow up this objective further. The phases of the anaerobic degradation process running synchronously in the sewage sludge substance mixture can be realised successfully in a reactor with little control expense.

In the past decades the thesis from FAIR and MOORE set up in the thirties that, for the digestion of sewage sludge, there were two operating ranges to be sought with associated optimum temperature ranges which, in practice, are to be maintained through appropriate control and temperature regulation measures, has established itself throughout almost all the textbooks and specialist articles. These are presented in Diag. 2.



Diag. 2: Dependency of the digestion time for the achievement of the technical digestion limit on the temperature (FAIR, MOORE 1934)

Numerous practical observations in various digester plants have, in the meantime, shown with sufficient certainty that the recorded activity maxima and minima of the anaerobic biocoenoses in practical operation do not have to be observed, rather that the reaction temperature with appropriate constraints can be matched to the respective thermal economy of the complete system of the sludge treatment.

In the summer months excess thermal energy produced can be utilised successfully to increase the temperature level in the reactor. The increased temperature level, in addition to an at least seasonal improvement of the success of stabilisation, also has the effect as heat store whereby the lowering of the process temperature in winter can be delayed significantly.

With continuous controlled changes of the digestion temperature no relevant drop in efficiency is to be feared as frequently was assumed previously.

With a dewatering of the anaerobically stabilised sludge one has to reckon with increasing degradation of the organic mass of solid matter with an increase of the nutrient loading (nitrogen, phosphorus with bio-P plants).

3 Influencing Factors with the Dimensioning of Plants

The biological stabilisation is dependent on many factors. Between these factors there are diverse relationships and dependencies which is the reason that they should not be considered in isolation but always in the overall context.

3.1 Raw Sludge Yield and Properties

For the dimensioning of a plant for separate biological stabilisation of the sewage sludge, the knowledge of the current and future raw sludge yield and its properties are of fundamental significance. On one hand this applies for the average loading of the sludge stabilisation plants with the DR and oDR daily loads produced, on the other hand for short- or medium-term additional loading as a result of external and internal factors. To the external factors are counted precipitation events, industries which function seasonally, tourism etc. With the internal factors the additionally yielded DR loads as a result of internal return loading of the wastewater treatment plant through sludge treatment also play a role.

Up until now, in practice, the determination of raw sludge yield and properties took place in accordance with the so-called “Sludge List” from IMHOFF (1999) which, depending on the different processes of wastewater treatment, listed the inhabitant-related DR loads for the raw and digester sludge yield. With regard to the adoption of the advanced wastewater treatment using further developed process technologies and various selected operating conditions it has shown, however, that over recent years in many cases the values given in the “Sludge List”, inter alia for reasons of necessary safety reserves, are too general and therefore should be considered differentiated.

A new approach to the determination of the basic sludge yield is presented below. With this it is possible, depending on the basic process and the respective operating conditions of the wastewater treatment, to carry out a systematic determination of the DR or oDR loads of the raw sludge as well as, if required, the surcharges to be applied. The raw sludge yield to be applied for dimensioning then results as the sum of the basic sludge yield and the appropriate surcharges of external and internal factors.

3.1.1 Determination of the Average DR and oDR Loads of the Raw Sludge Yielded (Basic Sludge Yield)

The **primary sludge yield PS** is applied according to the removal of the settleable solids (SS) in the primary settling stage. The relevant SS removal ΔSS depends essentially on the retention period $t_{R,PST}$ of the wastewater in the primary settling stage.

$F\text{-}DR_{PS} = F\text{-}SS_{IN} \cdot \Delta SS$ with:
$\Delta SS_{PS} = f(t_{R,PST})$

Typical values for the average SS removal depending on the retention time of the raw sludge in the primary settling stage are given in the Standard ATV-DVWK-A 131E (ATV-DVWK 2000). The *DR* content of the primary sludge removed from the primary settling stage (without return waste activated sludge) lies between 2 % and 8 %. The share of the organic solid matter *oDR* on the *DR* content (ignition loss *IgnL*) of the primary sludge as a mean is applied as 67 %. These details should if possible be verified by measurements.

The biological **waste activated sludge yield** $\boldsymbol{WS_B}$ with the activated sludge process is determined based on the formula tabled in Standard ATV-DVWK-A 131E (ATV-DVWK 2000) for the calculation of the waste activated sludge depending on the settleable solids in the influent to the aeration tank.

With this it is to be noted that the specific waste activated sludge yield with falling temperatures increases slightly. Therefore, principally a dimensioning temperature of 10 °C is relevant. As the wastewater loads relevant for the waste activated sludge yield are, as a rule, determined above the 85 percentile frequency of undercutting there is already a significant safety reserve compared with the annual mean sludge loads yielded. In addition, existing wastewater treatment plants as a rule show sufficient operating reserves for the buffering of loading peaks of the sludge yield (thickener, buffer tank or similar). In these cases it is permitted that the waste activated sludge yield is determined with an average dimensioning temperature of 15 °C.

The organic share oDR of the total share of solid matter of the waste activated sludge depends to a large degree on the sludge age in the aeration tank. With plants with low sludge age (t_{SS} < 5 days) the oDR content of the waste activated sludge as a mean is ca. 75 %. With high sludge age (t_{SS} > 15 days) this value can fall to 70 % as a result of the increasing share of the endogenous respiration.

The nutrient removal also has an effect on the waste activated sludge yield: with nitrification the share of newly formed nitrificants in the waste activated sludge is, however, so low that it practically has no significance.

The additional **waste activated yield** $\boldsymbol{WS_{DEN,ECS}}$ with denitrification by means of external carbon sources (e.g. methanol, ethanol, acetic acid) results depending on the NO_3-N load to be denitrified ΔNO_3-N (e.g. 4.5 g N/(g/(I·d)) and the external carbon source applied. The actual inhabitant-specific waste activated sludge yield from the denitrification using external carbon sources then results via the stoichiometric overdosing ß (as a rule = 1.35) as follows:

$F\text{-}DR_{DEN,ECS(METHANOL)} = 0.53 \text{ g DR/g } \Delta NO_3\text{-N} \cdot \Delta DN \cdot ß$

$F\text{-}DR_{DEN,ECS(ETHANOL)} = 0.82 \text{ g DR/g } \Delta NO_3\text{-N} \cdot \Delta DN \cdot ß$

$F\text{-}DR_{DEN,ECS(ACETIC ACID)} = 0.55 \text{ g DR/g } \Delta NO_3\text{-N} \cdot \Delta DN \cdot ß$

The waste activated sludge from the denitrification using external C sources increases the *SS* load of the biological waste activated sludge accordingly.

The additional **waste activated sludge yield** $\boldsymbol{WS_{BIO\text{-}P}}$ with the increased biological phosphorus removal, depending on the P load $\Delta P_{BIO\text{-}P}$ to be removed biologically is ca. 3.0 g SS/g $\Delta P_{BIO\text{-}P}$ (JARDIN 1995). The actual inhabitant–related waste activated sludge yield from the increased biological P removal then results as follows:

$F\text{-}DR_{BIO\text{-}P} = 3.0 \text{ g } DR\text{/g } \Delta P_{BIO\text{-}P}$

The waste activated sludge from increased biological P removal increases the *SS* load of the biological waste activated sludge accordingly.

The biological **waste activated sludge yield** $\boldsymbol{WS_{BF}}$ with biofilm processes (biological filters and biological contactors, biological filters, fixed and fluidised bed reactors) is fundamentally comparable with the waste activated sludge yield with the activated sludge process and is therefore, taking into account the appropriate operating parameters, to be determined quantitatively analogously to the procedure with the activated sludge process.

The **precipitation sludge yield WS_P** as a result of chemical phosphorus removal (simultaneous precipitation) results, dependent on the phosphorus load in the influent to the aeration tank, the specifications of the treatment performance (complete or supplementary chemical phosphorus removal through simultaneous precipitation) and the precipitant employed. The additional solids yield from precipitation products, in accordance with Standard ATV-DVWK-A 202E (April 2004) using iron salts is ca. 2.5 g DR/g Fe^{3+} or 4.0 g DR/g Al^{3+} using aluminium salts. The actual inhabitant-related increased yield of sludge then results via the required ß-factor [mol FM/mol P] of the precipitant input and the stoichiometric ratio of the mol masses of precipitant and phosphorus as well as the relevant phosphorus load in the influent to the aeration tank to be precipitated:

$$F\text{-}DR_{PREC(IRON\ SALTS)} = 2.5\ \text{g DR/g}\ Fe^{3+} \cdot ß \cdot 56/31 \cdot F\text{-}P_{tot,IN}$$

$$F\text{-}DR_{PREC(ALUMINIUM\ SALTS)} = 4.0\ \text{g DR/g}\ Al^{3+}\ ß \cdot 27/31 \cdot F\text{-}P_{tot,IN}$$

The organic share of the jointly removed biological waste activated sludge through the chemical precipitant sludge reduces accordingly.

Under certain circumstances a pH value correction is necessary though the input of hydrated lime due to the formation of H^+ ions with simultaneous precipitation using acidic metal salts. As here, with this addition of lime, one is concerned with regulation of a pH value in the almost neutral range, it is assumed that the hydrated lime is almost completely dissociated. With a lime precipitation, however, it must be calculated according to the selected dosing using precipitant products which are based on calcium carbonate or calcium phosphate.

The **sludge yield WS_{FF}** with a flocculation filtration placed downstream of the biological treatment stage is made up together from the precipitant products and the actual suspension retention. The sludge yield from the precipitant products can be estimated taking into account the phosphates and hydrates formed from the precipitant as ca. 2.5 g *SS* per g dosed iron (ATV 1997). If one applies for the precipitation some 5 g Fe^{3+} per m^3 wastewater as well as an average specific wastewater yield of ca. 200 l/(I·d), a specific sludge yield of ca. 2.5 g SS/(I·d) results from the precipitant products. The actual suspension retention is set as ca. 5 g SS/(I·d). The specific sludge yield from the flocculation filtration is thus ca. 7.5 g SS/(I·d).

The determination of yield and properties of the raw sludge (Basic Sludge Yield) is summarised in Table 3 below, depending on the process applied with the treatment of the wastewater and the selected operating conditions.

3.1.2 Surcharges as a Result of External and Internal Factors

With the quantities of sludge determined according to Sect. 3.1.1 one is concerned with the Basic Sludge Yield which results dependent on the loading of the wastewater treatment plant. Various internal and external influences described below lead, however, to higher quantities of sludge which are to be taken into account using appropriate surcharges.

3.1.2.1 Additional Sludge Yield as a Result of Precipitation Runoffs

The treatment of stormwater in the catchment area of the wastewater treatment plant can lead to a considerable additional sludge yield. The following influencing factors play a role:

area, topography, geology and surface degradation of the catchment area, deposits and flushing behaviour in the sewer network (in particular with combined systems), dimensioning, type and operation of the stormwater treatment facility.

As one is concerned mainly with mineral material with surface degradation and deposits in the sewer network, the *DR* share in the raw sludge increases. For the quantitative determination of the surcharges for the raw sludge yield as a result of precipitation runoff as far as possible operating data of the wastewater treatment plant concerned or comparable catchment areas with similar influencing factors should be employed. If this is not possible, surcharges of **20 % - 30 %** (on average 25 %) are recommended for pure combined sewer systems.

With modified combined sewer systems with smaller stormwater inflow the surcharges can be set correspondingly lower. With this, however, it should be taken into account that the precipitation water, above all from paved surfaces with slight pollution, should be kept away from the combined sewer and discharged directly. Thus the polluted precipitation runoff in the main continues to reach the wastewater treatment plant. The surcharge as a result of precipitation runoff should therefore not be reduced to the same degree which would correspond with the ratio of the paved surfaces, which are directly drained or can be drained via a combined sewer to the wastewater treatment plant. In addition the hydraulic flushing surge, which during and after rainfall loads the wastewater treatment plant in batches, is only slightly reduced through the modified combined system.

With catchment areas with separate sewer systems the surcharges for the increased yield of sludge as a result of precipitation events are set significantly smaller as, in the stormwater sewers one has to reckon with significantly less deposits. The sludge yielded results almost exclusively from the "degradation" of the surfaces of the catchment area and therefore consists almost completely of mineral components.

The additional sludge yield as a result of precipitant runoffs must be added as surcharge to the Basic Sludge Yield according to Sect. 3.1.1. Particular problems can be caused by the additional sludge from the treatment of stormwater through its yield in batches, which can reach far more than three times the daily sludge yield with dry weather. The difference in the timely distribution can be equally large and can lie between a few hours and several days.

3.1.2.2 Additional Sludge Yield as a Result of Seasonal Peak Loading

Industries which work seasonally (production of foodstuffs and beverages, wine campaigns) as well as the tourist season can lead at times to a considerable yield of raw sludge as a result of their additional wastewater pollution loads yielded over several months. The seasonal additional yield of sludge must be taken into account as soon as the hydraulic retention periods of the sludge with separated stabilisation are exceeded and no possibilities for intermediate buffering exist. Therefore the additional yield of sludge as a result of seasonal peak loads have to be taken into account with the dimensioning of the reactor volume of plants for sludge treatment in a similar manner to biological wastewater treatment. For this there are the following important options:

a) Appropriate enlargement of the reactor volume,

b) Retention of the reactor volume (acceptance of a temporary overload and reduction in efficiency according to the share of peak loading in the annual mean),

c) Combination of a) and b) as well a favourable arrangement of other influencing factors in particular thickening and or the possibilities for buffering.

To determine the dimensioning sludge yield the effects of seasonal loads for domestic and commercial-industrial wastewater must each be determined separately and taken into account using appropriate surcharges.

3.1.2.3 Additional Sludge Yield as a Result of Wastewater Treatment Works Internal Process Water

The organic and inorganic content substances incorporated in the primary and waste activated sludge are in part released with sludge treatment and, with the reduction in volume (thickening, dewatering) of the sewage sludge, return in mainly dissolved form with the separated sludge liquor as return flow into the biological stage. Depending on the type of sludge and the process of sludge liquor separation these highly concentrated internal pollutant loads often lead to a considerable additional loading of the wastewater treatment plant.

With **integrated joint treatment**, the wastewater treatment works internal process water from treatment of sludge yielded in the mechanical and/or biological treatment stage cannot be separately determined by means of the relationships presented in Sect. 3.1.1. As the raw sludge yield and its properties depend directly on the relevant wastewater loads in the inflow to the wastewater treatment plant as well as its removal through the respective treatment stage, a comprehensive balancing of the relevant wastewater, sludge liquor and sludge loads in the wastewater treatment plant is recommended for the determination of an accurate as possible total raw sludge yield.

Even with the realisation of a **separate treatment plant** for wastewater treatment works internal process water from sludge treatment additional sludge can, depending on the process, be yielded. This separate sludge yield can be determined separately by means of the relationships presented in Sect. 3.1.1 and is to be added as surcharge to the Basic Sludge Yield in accordance with Sect. 3.1.2. The return loading from a possible sewage sludge disintegration is to be taken into account analogously (MÜLLER et al. 2001).

Table 3: Raw sludge yield and properties dependent on various treatment processes and operating conditions

Process / Operating conditions		Sludge yield and properties			
	Type of sludge	*DR* content [% DR]	*DR* load [g /(I·d)]	*oDR*/*DR* [-]	Volume [l /(I·d)]
Primary settling tank:	Primary				
$t_{R,PST.}$ = 0.5 h [1a)]	sludge	2 - 8	30[1)]	0.67	1.0
$t_{R,PST.}$ = 1.0 h [1b)]	*PS*	2 - 8	35[1)]	0.67	1.2
$t_{R,PST.}$ = 2.0 h [1c)]		2 - 8	40[1)]	0.67	1.4
Activated sludge processes (T = 15 °C)	Waste acti-				
C removal (BOD_5+ if reqd. denitrification)	vated sludge				
t_{SS} = 5 d, $t_{R,PST}$ = 0.5 h	WS_B	0.7	46.3 [1) 2)]	0.75	6.7
t_{SS} = 5 d, $t_{R,PST}$ = 1.0 h		0.7	41.1 [1) 2)]	0.75	5,9
t_{SS} = 5 d, $t_{R,PST}$ = 2.0 h		0.7	35.8 [1) 2)]	0.75	5.1
t_{SS} = 10 d, $t_{R,PST}$ = 0.5 h		0.7	42.0 [1) 3)]	0.72	6.0
t_{SS} = 10 d, $t_{R,PST}$ = 1.0 h		0.7	37.3 [1) 3)]	0.72	5.3
t_{SS} = 10 d, $t_{R,PST}$ = 2.0 h		0.7	32.4 [1) 3)]	0.72	4.6
t_{SS} = 15 d, $t_{R,PST}$ = 0.5 h		0.7	39.3 [1) 4)]	0.70	5.6
t_{SS} = 15 d, $t_{R,PST}$ = 1.0 h		0.7	34.8 [1) 4)]	0.70	5.0
t_{SS} = 15 d, $t_{R,PST}$ = 2.0 h		0.7	30.2 [1) 4)]	0.70	4.3
t_{SS} = 25 d (Stabilisation plant)		0.7	56.2 [1) 3)]	0.65	8.0
Nitrification		Practically no WS additional production detectable			
Denitrification as result of ext. C sources	$WS_{DEN,ECS}$				
Methanol (ß =1.35)		1.0	5.7 [5)]	> 0.95 [6)]	0.57
Ethanol (ß = 1.35)		1.0	8.8 [5)]	> 0.95 [6)]	0.88
Acetic acid (ß = 1.35)		1.0	5.9 [5)]	> 0.95 [6)]	0.59
Biol. P removal	WS_{BIO-P}		2.75 [7)]	< 0.05 [7)]	
Biofilm processes					
Biological filters (C removal/nitrification)		Sludge yield and properties with biofilm processes, taking into account the respective operating conditions, result as analogous to the activated sludge process			
Biological contactors	WS_{BF}				
Fluidised bed reactors					
Simultaneous precipitation (SP)	Precipitation sludge				
Iron salts	WS_P				
ß = 1.0; $\Delta SF \approx$ 50 %			2.5 [8)]		
ß = 1.0; $\Delta SF \approx$ 100 %			5.0 [8)]		
ß = 1.5; $\Delta SF \approx$ 50 %			3.8 [8)]		
ß = 1.5; $\Delta SF \approx$ 100 %			7.6 [8)]		
Aluminium salts					
ß = 1.0; $\Delta SF \approx$ 50 %			2.0		
ß = 1.0; $\Delta SF \approx$ 100 %			4.0		
ß = 1.5; $\Delta SF \approx$ 50 %			2.95		
ß = 1.5; $\Delta SF \approx$ 100 %			5.90		
Flocculation filtration (FF)	Precipitation sludge				
Iron salts (ß = 1.5; $\Delta P_{tot} \approx$ 100 %)	WS_{FF}		7.5		

1. *SS* and BOD_5 loads in the raw wastewater are applied with typical values of 70 g DR/(I·d) or 60 g BOD_5/ (I·d).
1a) Typical removal rates: ΔSS = 43 %, ΔBOD_5 = 16.7 %
1b) Typical removal rates: ΔSS = 50 %, ΔBOD_5 = 25.0 %
1c) Typical removal rates: ΔSS = 57 %, ΔBOD_5 = 33.3 %
2. With a dimensioning temperature of 10 °C the waste activated sludge production increases by ca. 4 %.
3. With a dimensioning temperature of 10 °C the waste activated sludge production increases by ca. 5.5 %.
4. With a dimensioning temperature of 10 °C the waste activated sludge production increases by ca. 6 %.
5. The NO_3-N load ΔNO_3-N to be denitrified using external C sources is set as 8 g/(I·d) (e.g. after complete nitrification); with smaller ΔNO_3-N loads the waste activated sludge reduces proportionally,
6. The content of settleable solids in the effluent of the secondary settling tank is set as SS_{ESST} = 20 mg/l.
7. The P load ΔPBIO-P to be removed using bio-P, taking into account a P influent load of 1.8 g/(I·d), P removal in the primary settling tank of ca. 0.25 g/(I·d) ($t_{R, PST}$ = 1.0 h; $P_{x,PS}$ = 0.7 %), P incorporation in waste activated sludge (t_{SS} = 15 d; $P_{x,WS}$ = 1.7 %) of ca. 0.59 g/(I·d), an effluent load of 0.2 g P g/(I·d), is set as 0.96 g P/(I·d).
8. The P_{tot} load in the influent of the biological stage, taking into account a P influent load of 1.8 g/(I·d), the P removal in the primary settling tank of ca. 0.25 g/(I·d) and through incorporation in the biological waste activated sludge of ca. 0.59 g/(I·d) is set = 1.16 g/(I·d).

3.1.2.4 Additional Sludge Yield as a Result of Additional Substrates

The additional inhabitant-related sludge yield, due to the separate delivery of substrates such as faecal sludge or other organic substances (e.g. for co-fermentation), is determined separately. The value determined is to be added as surcharge to the Basic Sludge Yield in accordance with Sect. 3.1.2.

3.1.2.5 Peak Surcharges as a Result of In-plant Influencing Factors

The distribution of the sludge yield into a daily or weekly rhythm is determined from the process of the wastewater treatment plant. The process can be of considerable significance for individual elements of the treatment of the sewage sludge, which cannot be operated like stabilisation reactors in continuous operation. For the throughput capacity of many units and the retention period in buffer tanks working/operating days per week or per working day as well as arrangements for holidays are to be taken into account. Above all, with small and medium sized wastewater treatment plants without shift operation, these aspects are decisive for the dimensioning of the appropriate plant components. Consequently peak surcharges must be taken into for the design of individual units account as a result of in-plant influences.

3.1.2.6 Summary of the Possible Surcharges to the Basic Sludge Yield

The possible variations and peaks from internal and external influences are evaluated together and used as basis in a harmonious fashion for the dimensioning of the plant components. The necessary surcharges to the Basic Sludge Yield are summarised in Table 4.

Table 4: Surcharges to the basic sludge yield as a result of internal and external influencing factors

Influencing factors	Surcharge	Notes
Precipitation runoffs effect – taking up of the “pollution” in the catchment area – re-suspension of deposits in the sewer – erosion of the sewer film	Overall **ca. 20 % - 30 %;** otherwise consideration by case	If required further differentiation in accordance with the presence of “classical” or “modified” combined system; see also Sect. 3.1.2.1
Seasonal peak loads – industry – tourism	Consideration by case	Quantitative determination by means of Table 3 via separate balancing of the additional pollution loads in the inflow to the wastewater treatment plant (WTP)
Separate treatment of wastewater treatment plant internal process water	Consideration by case	Quantitative determination by means of Table 3 via separate balancing of the additional pollution loads in the process water from sludge treatment
Integrated joint treatment of WTP-internal process water in the wastewater treatment	Consideration by case	Quantitative determination by means of Table 3 via separate balancing of the **total** pollution loads in wastewater and sludge flows produced in the WTP
Separate input of substrates (faecal sludge, organic matter)	Consideration by case	Quantitative determination of the PT-specific DR or oDR-loads
In-plant influencing factors (peak surcharges)	Consideration by case	Determination of peak surcharges in accordance with operational specifications and constraints

3.2 Conditioning

3.2.1 Thickening

The sewage sludge resulting from the treatment of wastewater has a very high water content and a correspondingly small content of solid matter. Therefore, for all process steps of sludge treatment, a concentration of the solid matter with appropriate reduction of volume is sensible. This brings economic advantages in particular for the volume of the stabilisation reactor, the mixing and heating unit and the sludge dewatering machine.

With combined sludge thickening the solid matter contents which, as a rule, are too low for an optimum method of operation of the following treatment stages, are achieved through the joint thickening of primary sludge and waste activated sludge in the primary settling tank or in a static thickener. Therefore a *separate static thickening of the primary sludge* in the primary settling tank or in a thickener and the *mechanical thickening of the waste activated sludge* is carried out increasingly. The solid matter content in the thickened sludge should only be increased so far that the degradation process is not hindered and the operation of the transportation, circulation and heating is ensured, in the following stabilisation stage.

The basic elements and various processes of thickening are summarised in detail in the ATV Report „Eindickung von Klärschlamm“ [“Thickening of sewage sludge” (Not available in English)] (ATV 1998).

The respective quantity of water and in particular the intensity of the inter-molecular bonding force (electrostatic and Van-der-Waals forces) are critically dependent on:

- the distribution of particles, whereby the smallest particles have a very large specific surface area and thus very large bonding forces,
- the organic content substances which have a very high specific surface area,
- the colloidal and gel-like constituents which are contained in particular in organic waste activated sludge and in hydroxide sludge as well as in phosphate precipitation sludge,
- the share of filament-forming micro-organisms (e.g. Microthrix parvicella) as a result of the hydrophobic (water rejecting) properties),
- the share of EPS (extracellular polymer substances) as a result of slimy/viscous properties,

With biological wastewater treatment and sewage sludge stabilisation the degradation of organic substances reduces, above all the element of the colloidal and gel-like content substances with the exception of the EPS.

The results of thickening are essentially dependent on the composition of the wastewater, the process technology of the wastewater treatment and the sludge treatment.

The solid matter content of the discharge achievable using the different processes are summarised according to sludge types in the ATV Report „Eindickung von Klärschlamm“ (ATV 1998).

With static thickening a conditioning using organic flocculation aids as a rule leads to no important improvement of the degree of thickening; the solid matter-related degree of separation can, however, be increased.

As a rule, with conditioning, a degree of separation of more than 90 % can be achieved. Further details can be found in the above-named ATV Report.

3.2.2 Sludge Conditioning

Under sewage sludge conditioning are understood to be all processes which lead to an improvement of the thickening capability and dewatering capability of the sewage sludge with regard to the respective process goal.

Conditioning can be achieved via chemical and/or physical processes. The working mechanisms are explained in detail in the ATV Report „Auswahl und Einsatz von organischen Flockungshilfsmitteln – Polyelektrolyten – bei der Klärschlammentwässerung“ [“Selection and employment of organic flocculation aids – polyelectrolytes – with sewage sludge dewatering” (ATV 1992a) not available in English] and the supplement „Einstufung von organischen Flockungshilfsmitteln – Polyelektrolyten – in Wassergefährdungsklassen“ (ATV 1999) [“Classification of organic flocculation aids - polyelectrolytes – into water hazarding classes”; not available in English].

The effects of the flocculation aids on the advanced sludge stabilisation are currently under specialist discussion.

According to available operating results on an industrial scale and laboratory investigations, negative effects on the wastewater treatment and the sludge treatment can arise with the employment of an increased quantity of organic flocculation aids with the pre-thickening of the waste activated sludge due to the chemical composition, the degradation behaviour and the charge balancing which takes place with thickening. Within the anaerobic sludge stabilisation and dewatering, as a rule, one has to reckon with a

- reduction of the yield of biogas and a
- worsening of the digested sludge dewatering characteristics with the result of a smaller discharge solid matter content and an increased requirement for conditioning agent.

3.2.3 Changes of the Rheological Sludge Characteristics

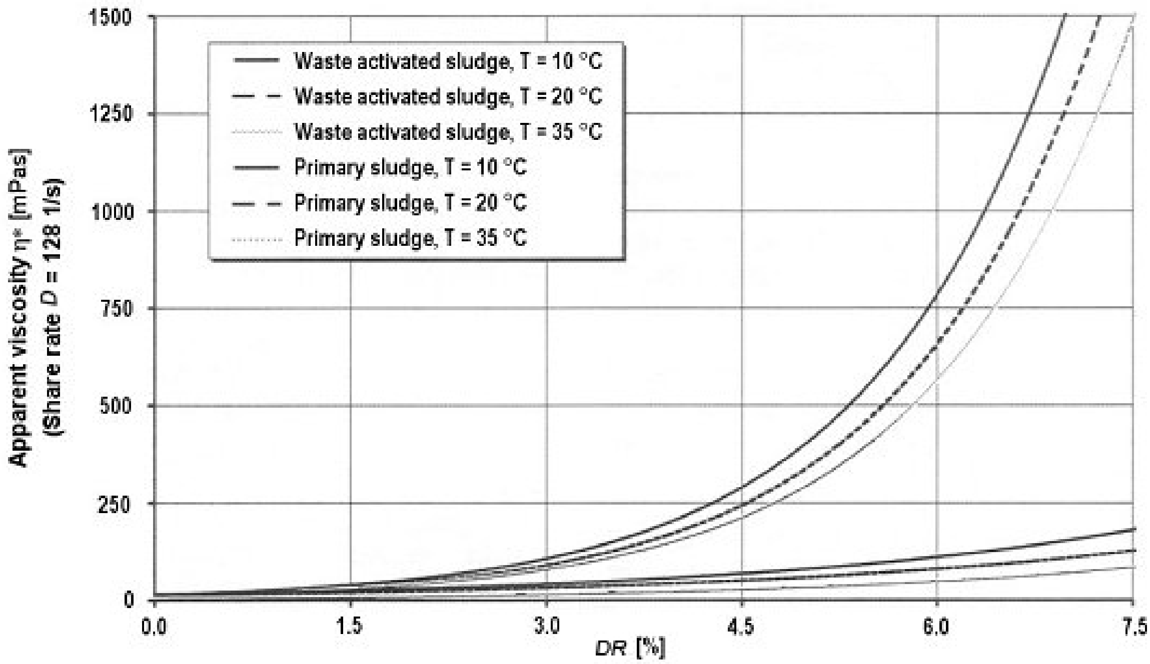
The rheological characteristics (flow characteristics) of sewage sludge change with thickening. They are described using the measured value of the viscosity. With this, raw sludge and digested sludge are to be classified as non-Newtonian liquids, as they change their viscosity depending on the forces acting on the liquid. With the evaluation of the flow behaviour the sludge is to be divided into primary and secondary sludge, raw sludge and stabilised sludge. Here, the solid matter content, the share of organic substance, the degradation of colloids with stabilisation and the temperature have a decisive influence on the viscosity.

Viscosity investigations of activated sludge with a solid matter content of 2 - 8 gSS/l resulted in no important deviations in comparison to clean water. Equally, with conventional static raw sludge thickening to a solid matter content of 2 % to 4 % *DR*, no significant influences on the flow behaviour were ascertained (Bau, 1986).

The flow capability first deteriorated following the mechanical thickening of raw sludge and the mechanical thickening of waste activated sludge using centrifuges without addition of flocculation aids (DENKERT 1988). The apparent viscosity for the separate thickening of primary and secondary sludge using centrifuges was investigated by BAU (1986). The results are presented in Diag. 3 in dependence on solid matter content and temperature.

The viscosity of the pre-thickened sewage sludge as a rule improves in the subsequent stabilisation plant dependent on:

- stabilisation process
- stabilisation temperature
- stabilisation time
- share of waste activated sludge of the total quantity of raw sludge
- degradation of the colloids
- share of the finest solid matter particles.



Diag. 3: Influence of the solid matter content and the temperature on the flow behaviour (apparent viscosity) of primary and secondary sludge

The viscosity must be taken into account with the pipe friction losses, with the selection of pumps for transport of the thickened sludge and the conception of the mixing facilities in the stabilisation plant. There are also limits for the raw sludge thickening due to the viscosity as negative effects on the subsequent stabilisation should be avoided.

3.3 Influences of Sewage Sludge Disintegration

In the digester the biological degradation reactions start with hydrolysis, whereby the organic components in such compounds are broken down and converted, which are then in part or colloidally soluble in sludge liquor. The speed of this degradation reaction is determined through the formation rate of the enzymes required for this. Here the disintegration of the sludge begins. If one destroys or disintegrates the cell walls of the micro-organisms in the sewage sludge the cell components are then available for the enzymes. Intracellular enzymes then additionally can also take part in the degradation reactions.

With mechanical disintegration the energy is introduced into the sewage sludge mechanically. For this one utilises the methods from wet crushing technology or from the dispersion and emulsion technologies. Currently employable are agitator ball mills, high pressure and shear splitting homogenisers, ultra sonic disintegrators and centrifuges with lysing facilities. The disintegration or treatment can be induced through non-mechanical methods (thermal, chemical, biological).

For practical purposes the disintegration is carried out on the waste activated sludge as this, to a large extent, consists of micro-organisms.

The effects of the sewage sludge disintegration on the anaerobic sludge stabilisation can be the following:

An acceleration of the biological degradation process can take place which, theoretically, can lead to a reduction of the retention time in the digester.

The degradation of the organic elements in the sewage sludge can be increased from ca. 40 % to 60 %. Consequently the specific biogas yield can increase. The remaining quantity of sewage sludge reduces after dewatering.

Attention is to be paid that the retention time in the digester is not set too short due to the accelerated degradation with continuous charging, as then a washing out or removal of the active biomass from the digester can occur.

The reduction in the size of the sewage sludge particles through disintegration influences even more parts of the wastewater treatment plant operation. Thus, for example, the dewatering behaviour can deteriorate and the consumption of flocculant usually increases significantly. The increased solubility of organic substances in the sludge liquor leads to a return loading of the activated sludge stages.

Further information on this subject can be found in the reports of the ATV-DVWK Working Group “Disintegration of Sewage Sludge” (ATV-DVWK 2001, 2001a; ATV 2000)

4 Process, Dimensioning and Operation of the Biological Stabilisation

4.1 Aerobic Stabilisation

The aerobic stabilisation of sewage sludge, whose biochemical basic elements are described in Sect. 2.2.1, can be realised process-technically essentially using the following process variants:

- simultaneous aerobic sludge stabilisation;
- separate aerobic sludge stabilisation with normal, mesophilic and/or thermophilic temperature ranges;
- sludge composting (separate aerobic sludge stabilisation with thermophilic temperature ranges into a solid or non-flowing aggregate state).

The process technologies named are described below. The most favourable employment ranges of the processes are presented in Chap. 6. Notes on stabilisation characteristic values are contained in the ATV Report „Stabilisierungskennwerte für biologische Stabilisierungsverfahren" [“Stabilisation characteristic values for biological stabilisation processes”; not available in English] (ATV 1994), as well as in Handbooks No. 2-3 and No. 2-4 of the ATV-DVWK Federal State Association Bayern (ATV-DVWK 2003).

4.1.1 Simultaneous Aerobic Sludge Stabilisation

With simultaneous aerobic stabilisation the settleable solids (primary sludge) which reach the wastewater treatment plant with the raw wastewater and the waste activated sludge formed with the biological wastewater treatment in accordance with the activated sludge process are stabilised simultaneously in a reactor in a process step with the biological removal of carbon and nitrogen compounds. The primary settling stage is dispensed with. For an extensive stabilisation of the sludge a high sludge age is necessary, which can be realised process-technically through a long aeration time and a sufficiently high activated sludge content in the simultaneous aeration or stabilisation tank.

The dimensioning of the simultaneous aerobic stabilisation takes place using the Standard ATV-DVWK-A 131E (ATV-DVWK 2000). The following approaches serve for a rough pre-dimensioning:

- sludge age $t_{SS} \geq 20$ d
  (temperature T ≥ 10 °C; with nitrification)
- sludge age $t_{SS} \geq 25$ d
  (temperature T ≥ 10 °C; nitrification and deliberate denitrification)
- activated sludge content in the stabilisation tank SS_{AT} = 4 - 5 kg SS/m^3
- oxygen load $O_B \geq 3.0$ kg O_2/kg BOD_5

The accurate determination of the average *SS* content in the stabilisation tank SS_{AT} takes place under specification of treatment goal and sludge volume index *SVI*. The necessary oxygen transfer αOC_{nec} is determined depending on various influencing factors (wastewater properties, treatment goal peak loading conditions) using Standard ATV-DVWK-A 131E (ATV-DVWK 2000). Structural design and process technical design of the stabilisation tank is oriented on the corresponding wastewater engineering process variants, which are presented in detail in the ATV Manual on Biological wastewater treatment (ATV 1997).

Advantages result from the low investment costs and the operational security (large buffer capacity) as well as the low operating and monitoring expenditure. In addition, the formation of an anoxic area for denitrification is possible without problem. In order not to endanger the process goal of stabilisation and to prevent the formation of bulking sludge, the aeration time may not undercut 65 % – 70 % of the total time. The operating costs as a result of the long aeration time are relatively high. In comparison with separate aerobic or anaerobic stabilised sludge, the thickening ability and dewatering capability are significantly poorer, in particular if the sludge is not completely stabilised due to the process (for the simultaneous running wastewater treatment still active activated sludge is still required). These disadvantages can be compensated using sludge ponds or other storage tanks for anaerobic post treatment.

4.1.2 Separate Aerobic Sludge Stabilisation at Normal Temperature

With separate aerobic stabilisation the raw sludge yielded with the treatment of wastewater (primary and waste activated sludge) is treated separate to the wastewater treatment in open, aerobically operated tanks or reactors at normal outside temperatures. As a result of the absence of insulation, with central European conditions, there is practically no measurable self-heating of the sludge through the exothermal metabolic processes with the aerobic degradation of the sludge content substances.

The dimensioning takes place via the necessary aeration time. The following guidance values are given (RIEGLER 1989, ATV 1996):

- retention period $t_R \geq 20$ d (Minimum temperature $T \geq 10$ °C),
- operationally necessary solid matter content in the stabilisation tank 3 % – 4 % *DR*,
- required aeration capacity *OC* ≥ 2.2 kg $O_2/(m^3 \cdot d)$ (*oDR* degradation ≈ 30 % - 35 %),
- required power density for aeration and thorough mixing $N_R \geq 50$ W/m^3.

Centrifugal aerators or coarse bubble compressed air aeration systems are suitable for aeration. The stabilisation tank, as a rule, is charged with raw sludge once a day. Prior to this the stabilised sludge is drawn off. The personnel expense is slight for operation and maintenance. Compared with aerobic-thermophilic stabilisation separate aerobic stabilisation with normal temperature is a little less efficient due to the lower degradation rates and is thus not so economical. The process is therefore no longer realised in Germany. In warm climate zones the employment of the process, however, appears to be thoroughly justified.

4.1.3 Separate Mesophilic and Aerobic-thermophilic Stabilisation

Through the creation of appropriate process-technical constraints (heat insulation of the reactors, thickening of the raw sludge, employment of suitable aeration and mixing units), the heat loss is so greatly reduced with the aerobic-thermophilic stabilisation that a self-heating of the sludge into the thermophilic temperature range of 45 °C – 65 °C is achieved. Metabolic rates and degradation performances are significantly increased with these temperatures (LOLL 1974, DEMHARTER 1986). The stabilisation time can thus be reduced. As a result of the higher temperature level a safe disinfection of the stabilised sewage sludge is possible (STRAUCH 1980). As a result of the very versatile aerobic biocoenosis the process, compared with toxic content substances in the sewage sludge, is relatively insensitive.

The dimensioning of the required reactor volume takes place via the hydraulic retention time of the sludge in the aerobic-thermophilic reactor (AT-reactor). For a perfect stabilisation of the sludge a retention period of at least five days is seen as sufficient (LOLL 1984, GLASENAPP 1989). This approach applies for thickened municipal raw sludge with ca. 70 % organic share and solid matter content of at least 3.5 % to 4.0 % *DR*. With static thickening of the primary sludge and separate mechanical thickening of the waste activated sludge the achievable *DR* content in the raw sludge as a rule lies in a favourable range between 5.0 % and 7.0 %. A too extensive pre-thickening of the raw sludge from more than 8.0 % to 8.5 % *DR* is not sensible as, due to the higher solid matter content, the viscosity of the sludge increases strongly. Oxygen transfer and thorough mixing in the reactor are then impaired considerably. According to available experiences, the aerobic biological degradation process is not negatively influenced by the employment of flocculation aids with mechanical pre-thickening.

The aeration and thorough mixing of the reactor contents with aerobic-thermophilic stabilisation can take place through combined aeration and mixing systems as well as separately pressure using systems with separate mixing facilities. As required combined systems can also be equipped with additional mixing facilities. The following systems are basically suitable:

- spiral and forced air aeration systems (self-priming ejector aerator),

- submerged aerators,
- binary nozzle aeration systems (injector aerators),
- pressure aeration systems with separate thorough mixing facility.

Surface aerators are not suitable as the heat balance is influenced negatively and the insulating foam layer is destroyed through the input of air via the surface.

The dimensioning of the aeration systems with aerobic-thermophilic stabilisation can be determined sufficiently accurately via the balancing of the chemical oxygen demand COD. With this it is assumed that the COD reduction corresponds approximately with the microbial oxygen consumption (BAU 1986). The relevant air supply can be determined roughly via the following approach:

$$Q_A = \frac{1.2 \cdot 3.367 \cdot COD_{Raw} \cdot \alpha \cdot V_R}{\Delta O_2 \cdot t_R \cdot 24} \quad [m^3/h]$$

with:

1.2	[kg O_2/kg COD_{deg}]	Safety factor for degradation-specific oxygen consumption
3.367	[m^3 Air/kg O_2]	Conversion factor = f(T, p); (T = 0 °C, p = 1013 hPa)
COD_{Raw}	[kg/m^3]	COD concentration in the raw sludge
α	[-]	degree of COD degradation
V_R	[m^3]	Reactor volume
ΔO_2	[-]	Average oxygen utilisation of the aeration system
t_R	[d]	Stabilisation goal
24	[h/d]	Conversion factor

The required energy expenditure for the thorough mixing of the reactor contents is proportional to the flow behaviour of the sludge. In order to ensure a sufficient thorough mixing, an expenditure of energy corresponding to the viscosity of the sludge is necessary. The following reference values apply for the required power density in the reactor N_R (Table 5):

Table 5: Required power density N_R depending on the DR content of the reactor sludge

Raw sludge pre-thickening	$DR_{RawSludge}$ [%]	$DR_{ReactorSludge}$ [%]	Power density N_R [W/m^3]
Static	3.5 - 4.0	2.0 - 2.5	80 - 100
Mechanical	5.0 - 6.5	3.0 - 4.0	120 - 180

Due to the non-Newtonian behaviour of the thickened sewage sludge the creation of an even and high shear gradient in the reactor is of considerable significance for the oxygen supply. If possible, two or more mixing units each with relatively low specific power consumption should be distributed evenly in the reactor. In view of the process-technical diversity of the aeration and mixing systems on offer it is, in principle, recommended that before any decision is made on the system, independent information on the oxygen-transfer capacity, on the required energy consumption and on the technical functional capability of possible systems is obtained.

For technical flow reasons the aerobic-Thermophilic (AT) reactors should have a cylindrical form. To minimise the radiation losses a tank geometry with a ratio between internal diameter of the reactor *D* and height of sludge level *H* of 1.0 is optimal. In practice the *H*/*D* ratio is, however, dependent essentially on the structural design of the aeration and mixing system selected. For spiral aerators a *H*/*D* ratio of 0.5 is favourable. The aerators are installed tangentially to the reactor wall with a 45 % slope to the reactor bottom. Forced air aerators are arranged centrally whereby the *H*/*D* ratio is also to be 0.5. Submerged aerators are also to be arranged centrally. In view of the intensive thorough mixing at the bottom of the reactor *H/D* ratios of 0.75 to 1.0 are certainly possible. As a result of the lesser dependency of the air supply on the filling level of the reactor, *H/D* ratios of 1.5 to 2.0 or higher can be favourable for better oxygen utilisation with binary nozzle aeration systems. This applies also for compressed air aeration systems with separate thorough mixing facility.

With aerobic-thermophilic stabilisation a very fine and dense foam layer is formed through the exhalation of CO_2 or of air, whose height for operating reasons has to be limited. The height of the permitted sludge layer above the sludge level is dependent on the system. With spiral, forced air and submerged aerators the height of the foam layer formed should be limited to a maximum of 0.15 m. With binary nozzle and compressed air aeration systems higher foam layers are certainly permitted. The permitted height then conforms essentially to the reactor geometry and the desired freeboard in the reactor.

With smaller plants the installation of a single reactor for aerobic-thermophilic stabilisation suffices. With medium and larger units several reactors in series are to be installed. Two-stage plants have proven themselves to be very good operationally. More than three reactors in series are not recommended. In order to ensure a high operational flexibility of the stabilisation plant with the employment of several reactors these should be of the same structural design and connected appropriately using pipelines.

As a result of material stress and strain with high operating temperatures the tanks are constructed mainly of steel. The tanks must be well protected both internally and externally against corrosion. Heat losses are sufficiently reduced if the tanks are insulated with a ca. 10 cm thick heat insulation with a caloric conductibility of ca. 0.04 W/(m·K).

With the start-up of an AT plant no seeding of the sewage sludge is required; the process comes into action so rapidly that already after three to four days an average temperature level of ca. 55 °C and more can be achieved. After achieving the desired temperature level the charging with small- and medium-sized plants should takes place once or twice a day. This method of operation ensures the necessary minimum retention period for the disinfection and has proven itself to be very good in practice. With larger plants with several reactors the charging can be evened out through automatically controllable dosing pumps or through continuous pump operation. Before charging, the raw sludge should be stored intermediately for a short time only. Otherwise one has to reckon with a significant pre-degradation of the organic substance as well as considerable odour nuisance as a result of the uncontrolled onset of acidic fermentation.

For operational control as well as for the regulation of the process the parameters reactor temperature, pH value and oxygen content come primarily into consideration. In practice it has been shown that a sufficient operational control of temperature and pH value is possible.

The pH values, with normal operation, vary between 7 and 9. A pH fixing is not required. The average daily temperature in the reactor varies depending on the manner of operation, raw sludge temperature and external temperature between 40 °C and 65 °C. Above ca. 65 °C the specific efficiency of degradation of the aerobic-thermophilic biocoenosis, which consists mainly of spore-forming bacteria, reduces. Therefore it is recommended that this temperature range is avoided through the easing of the oxygen transfer. A further regulation of the temperature is not necessary, as the aerobic-thermophilic biocoenosis possesses a high adaptability to temperature variations. With discontinuous operation the reactor temperature displays a saw-tooth progression. The difference between the daily minimum and maximum temperature can be more than 10 °C.

With aerobic-thermophilic stabilisation the BOD_5/COD ratio has shown itself, inter alia, to be a suitable parameter for the determination of the degree of stabilisation. Municipal sewage sludge can, as a rule, be seen as stabilised if the BOD_5/COD value is ≤ 0.15. With special constraints a BOD_5/COD value of ≤ 0.10 can be required. As further possible parameters for the determination of the degree of stabilisation, the determination of the respiratory activity ($OV \leq 100$ g O_2/(kg·oDR·d)) and, if required, the determination of the content of organic acids in the stabilised sludge come into consideration.

4.1.4 Sludge Composting (Separate Aerobic-thermophilic Stabilisation in Solid or Non-free-flowing Aggregate Condition)

The aerobic-thermophilic stabilisation, as has been described in Sect. 4.1.3, can be operated also in solid and non-free-flowing aggregate conditions which is equivalent, biologically and process-technically, to composting.

The composting process or the biochemical degradation process also called rotting can take place, both with extensive mechanically dewatered raw sludge alone as well as in a mixture with other biogenic waste matter.

What is decisive is that the heap to be ventilated is loosened to such an extent that sufficient air or oxygen reaches all parts of the reaction volume.

In order to ensure this, with normal sewage sludge composting reactors, structured materials such as, for example, saw dust or paper remains, which are often described in literature falsely as C-donors, are added to the raw sludge which is to be stabilised.

The addition of carbon sources is in no way necessary for the actual biological conversion process which is shown clearly with stabilisation in a fluid environment both with the aerobic as well as with the anaerobic process.

Analogous to other composting process techniques the complete process of biological stabilisation is carried out usually in two phases.

In the first phase a so-called pre- or intensive rotting under thermophilic temperature conditions is set, whereby here more than 60 °C are to be maintained for practical reasons over a longer period.

The process duration of the intensive rotting should be at least 14 days. To accelerate the respective rotting process and also for the improvement of the structural boundary conditions of the material to be stabilised, in many cases fines are fed back into the rapid rotting process.

In a final post-rotting the biologically highly active material is subjected to a post-rotting process which is to be dimensioned in at least weeks, however usually in months, with which the remaining stabilisation work is to be performed.

The process step of intensive rotting can be carried out technically in so-called bioreactors quasi continuously or in rotting cells by charges.

For the quality characteristics and for process controls the same criteria apply as for the composting of other biogenic wastes.

Further technical information is to be found in the ATV Handbook „Klärschlamm" (ATV 1996).

4.2 Anaerobic Stabilisation (Sludge Digestion)

Under sludge digestion is understood to be the anaerobic degradation of organic sludge content substances (EN 1085, 1997). The biochemical basic elements of the anaerobic stabilisation are described in Sect. 2.2.2.

The anaerobic degradation of the raw sludge effects a considerable reduction of solid matter. Approximately half of the organic matter contained in the raw sludge is degraded. In addition, the process produces biogas/digester gas which can be utilised as energy carrier.

The areas of application of the process dependent on the economic efficiency as well as other constraints are defined in Chap. 6.

4.2.1 Process Alternatives

With sludge digestion one can differentiate basically between the following reactor types:

- open or closed digesters,
- unheated or heated digesters.

Open and unheated digesters are today still employed only in very simple conditions or in warm climate zones. They are therefore not dealt with in any detail other than to give a few dimensioning sizes in the dimensioning part (Sect. 4.2.2).

Due to the dependency of the digestion time on the temperature (see Chap. 2.2) the heating of the sludge in closed tanks leads to a significant reduction of the necessary treatment volume.

Heated anaerobic stabilisation in closed digesters can be operated as:

- mesophilic digestion in a temperature range between 30 °C and 40 °C or as
- thermophilic digestion in a temperature range between 50 °C and 60 °C.

For disinfection, reactor temperatures > 55 °C are to be maintained.

Mesophilic anaerobic sludge stabilisation is by far the most frequently employed process.

Anaerobic sludge digestion can be operated as single-stage – with several tanks in parallel operation – or as two-stage. With two-stage operation the first highly loaded anaerobic stage serves for the hydrolysis and acidification of the substrate introduced. If, for example, problems are to be expected through particular industrial loading or toxic loads, the two-stage operation has the advantage that the loading peaks are made noticeable well in time through the falling gas development of the first tank. The still functioning second tank can then process the raw sludge yielded for some time alone until the first digester has "recovered". The disadvantage is that, with the same tank size, the operationally relevant volumetric loading in the first tank is very large, while it is always small corresponding to the in the meantime degradation achieved for the following tank. Thus the utilisation of space also reduces which is considerably better with parallel charging due to the more even loading. In practice both methods of operation are employed with success.

4.2.2 Dimensioning

Already for some time there have been efforts to determine the digester volume using calculation models. Due to the numerous influencing factors such as, for example, yield of raw sludge, temperature, thorough mixing, sludge content substances as well as their mutual influence, up until now the degradation kinetics have not been capable of being grasped accurately.

Digestion is an asymptotic biological degradation process whose last phase stretches to a very long time so that this is finally of no significance technically. The process is therefore broken off at a (certain) point, which is designated as technical digestion limit.

This technical digestion limit is, however, no precisely fixed value, but rather depends on various constraints as well as on different criteria for the assessment of the stabilisation process. Above all to these belong the degree of stabilisation, gas production, dewatering capability of the digested sludge, reduction of odour, content of organic acids.

As these characteristic values, with regard to their being taken into account optimally, lead to different results, a compromise usually has to be selected for dimensioning. So far as this is possible, pre-trials with the sewage sludge yielded should be carried out for this – in particular with existing plants – in order to be able to record the specific sludge characteristics.

Relevant dimensioning parameter is the digestion retention time. The following digestion times are selected as approximate values (see also Chap. 2.2).

- earth basins and unheated digesters 120 days
- Imhoff tanks 60 days
- heated digesters (35 °C) 20 days
- heated digesters (55 °C) 12 days

In order to be able to buffer loading peaks sufficiently, a retention period with mesophilic digestion of at least 20 days is recommended. The Specialist Committee strongly advises against a realisation of significantly shorter digestion times, as is more often recommended in recent times, as this endangers the assured guarantee of the goal of stabilisation.

The dry residue of the raw sludge should be 3 % to 8 %. A sufficiently thorough mixing of the tank volume is to be ensured, in particular for higher solid matter contents.

For a sufficient but at the same time economic dimensioning of the digesters it is necessary, in addition, to procure an as accurate as possible overview on the amounts of sludge yielded and their water content. For wastewater treatment plants which already exist, the hydrographic curves of the sludge yield can be evaluated for this.

Here the maximum daily peak values are not to be taken into account, rather the determination of the sliding average values dependent on retention time and to subject these to a highest value consideration. With new planning it is also necessary to make sensible assumptions in how far the sludge quantities can vary over the year in order thus to be able to verify a secure retention period in the digester dependent on a realistic maximum.

With the observation of the above given digestion time and correct operation and equipment of the digester one has to reckon with a degradation of the organic solid matter mass of ca. 45 % – 50 %. With municipal wastewater treatment plants without significant industrial discharges one has to reckon with a specific digester gas production of ca. 400 – 500 l per added kg oDR. This digester gas production is determined decisively by the following influencing factors:

- digestion time,
- digester temperature,
- digester circulation,
- share of the waste activated sludge quantity in the overall raw sludge quantity,
- operation and utilisation of the wastewater treatment,
- sludge age, sludge loading
- phosphorus precipitant – type and quantity.

With the joint treatment of organic substrates the specific digester gas production rate changes.

More details on the composition and utilisation of digester gas are described in Advisory Leaflet ATV-DVWK-M 363 (Not yet available in English) (ATV-DVWK 2002a).

4.2.3 Structural- and Process-Technical Constraints

Conspicuous characteristic of wastewater treatment plants with aerobic sludge stabilisation is, as a rule, one or more cylindrical, egg-shaped or spherically matched closed digesters above ground level made from steel, reinforced concrete or prestressed concrete. Therefore in the past, with the construction of digesters, not only structural and foundation technical specifications as well as operational functions have played a role but also, too often, architectural considerations.

4.2.3.1 Structural Shapes

Favourable, selected shapes can support good thorough mixing, work against bottom deposits, reduce scum layer problems and also ease gas collection.

The classical, continental European shape is made up of a cylindrical middle part (D:H~1) and a lower and upper cone. If one selects the incline for the lower cone as 1.0 to 1.7 and for the upper cone as 0.6 to 1.0, then this shape offers good prerequisites for the circulation/homogenisation of the tank contents.

The egg form represents a further improvement of the classical European shape; it first became possible through progress in concrete technology. Through the steep lower trough, the small sludge surface and the continuous curvature of the wall, this shape delivers extremely favourable preconditions for circulation. In addition, the ratio surface/content with a view to the required heating is more favourable than with the other structural shapes.

The cylindrical shape with flat bottom represents a compromise between the Anglo-American (D:H>1) and the classical European shape. It is cheaper to produce and has a more favourable $D:H$ ratio. In particular the flat bottom leads, nevertheless, to limitations with the selection of the mixing facilities.

4.2.3.2 Equipping

The required security which is to be taken into account with the dimensioning of digesters depends, above all, on the effectiveness of the technical facilities employed. The preheating and seeding of the raw sludge with charging, the circulation of the contents of the digester as well as a continuous heating are the essential prerequisites for an intensive digestion process. In addition, the possibility must exist to monitor and control the process and also to be able to be able to intervene with malfunctions.

The installation of the technical equipment should as far as possible take place outside the digesters.

4.2.3.3 Charging and Seeding

As far as possible digesters are charged with raw sludge which has a relatively high solid matter content in order to save digester volume – and thus heating energy.

The charging of the digester should, within the meaning of an optimum reactor, take place as far as possible continuously. What is to be sought here is to preheat the raw sludge extensively to the tank temperature and to mix in, i.e. to seed, using several times the inflow quantity of active sludge.

A continuous operation with smaller plants runs up against limits inter alia with regard to a minimum pipeline cross-section so that then a quasi continuous interval operation is to be sought.

If the digester – as is today generally usual – is operated as anaerobic biological flushing reactor then, at the same time as the input of raw sludge the appropriate quantity of digested is forced out of the reactor.

4.2.3.4 Circulation

A sufficiently intensive circulation ensures the required material and heat transport, the prerequisite for the degradation of the organic substances and the gas development as well as an even distribution of temperature in the complete sludge mass. The chronological and local constancy of solids, bacteria and temperature and the utilisation of the whole available space are therefore to be sought (totally thoroughly mixed tank), i.e. dead space and short circuit flow are to be prevented.

For circulation in digesters, primarily the following processes are employed:

- external pumps,
- large type screw pumps / digested sludge mixers,
- stirring devices,
- gas lifting.

The circulation of the digester contents via external pumps represents a very simple process which is available in particular for smaller tanks. With large tanks the quantity to be circulated is distributed over several pumps. Currently digesters up to ca. 4000 m^3 are equipped with this system, whereby however, according to EN 12255, Part 8, for digesters > 500 m^3 the external circulation is seen as insufficient.

The so-called large type screw pump consists of the rising pipe, the fixing device, the actual mixing organ with deflector plate and the drive. The rising pipe, depending on the tank size, is connected to the tank wall and centred over its height at several points using rods or cables. Single- or two-stage, specially developed impeller wheels, which can transport in both directions, have proved themselves as mixing organs. A deflector plate, with upwards transport, serves as aid for the distribution of the sludge on to the scum layer and, with the transport direction downwards, to steer the broken up floating sludge into the rising pipe.

Due to problems with tangling/matting internal stirring devices have been used relatively seldom in Germany. In order to avoid an emptying of the digester due to defective units, fundamentally no moving parts which cannot be easily removed should be present within the digester. Recently, however, due to the lower investment costs, internal stirring devices have been increasingly employed.

Gas lifting is also a proven process for reactor circulation. The gas is compressed and forced via various systems into the lower part of the digester. Through the rising gas bubbles an upwards flow and, as a result of this, at other points an appropriate downwards flow, i.e. a circulation is created. Here, at the same time, the formation of the scum layer is counteracted; a possible existing inclination of the sludge to foam is, however, reinforced. With tanks with funnel points it is recommended that digester gas is injected at the periphery so that the sludge in the area of the reactor outer wall is moved upwards and, in the centre, downwards. With tanks with flat bottoms – due to the hydrostatic conditions these are above all suitable for gas lifting – the gas is fed through several rigid or, better, flexible lances, which can be dismantled (removed) upwards, down to immediately above the bottom.

In order to ensure a sufficiently thorough mixing it is necessary that at least five-times the digester contents are circulated daily. With regard to the digested sludge, thickening and dewatering processes should as far as possible be employed which subject the digested sludge flocks to a not too high shear loading.

The required power density for an effective circulaton of the contents of the digester lies, dependent on the solids content in the reactor and the size of the reactor, between ca. 5 – 15 W/m^3. It can most conveniently be achieved using digester gas mixing, with external circulation the hydraulic pipe losses lead to an increased energy demand.

4.2.3.5 Heating

The methane bacteria can react sensitively to short-term changes in temperature, so that this is as far as possible to be maintained or to be changed slowly. The digester heating today takes place, as a rule, via external heat exchangers. Alternatively, in more rare cases, internal heating exchangers or a direct low pressure steam heating is also employed.

The performance of the heating system is to be so dimensioned that, even in winter with low raw sludge temperatures and low external temperatures, a secure heating up of the raw sludge is guaranteed taking into account the radiation losses.

Within the scope of an economical operation of the digesters it is recommended to heat up these before the winter period using the then still sufficient existing digester gas or usable waste heat to temperatures of ≥ 40 °C, in order with this to be able to utilise the thus stored heat energy in the colder season. With this the heat insulation of the tank is also of great significance. In addition, the static constraints of the tank are to be examined beforehand, in particular with operation using even higher temperatures.

The supply of heat to the heat exchanger as a rule takes place from the complete heating system, which is provided through a boiler plant, a gas motor plant or from a combination of both. For the purposes of a heat supply which is ensured at all times – the digester has to be started up, furthermore the failure of the energy carrier digester gas must be calculated for – the holding of a second energy source for the operation of the boiler is necessary; for example:

- oil,
- natural gas/propane gas.

Under certain constraints the employment of a sludge-sludge heat exchanger (recuperator), also with mesophilic operation, can be an economical alternative for heat recovery by preheating the raw sludge by ca. 10 °C – 15 °C, in particular when, due to other energy users, outside energy must be employed.

4.2.3.6 Facilities for Measurement and Control

Independent of legally prescribed records, measuring and registration equipment is to be installed and manual measuring equipment is to be held in case of need for the evaluation of the quality of the process as well as for the overview of quantities and energy.

Important are in particular measurements of temperature, pressure, pH value, sludge quantity and digester gas quantity. The gas quality is to be checked using the appropriate analysis equipment. In addition, various measurements for general monitoring of operation such as filling level measurements or operating hours counter can be planned.

4.2.3.7 Operation

With regard to the operation the following are to be differentiated: commissioning, normal operation and operating faults.

For commissioning the digester is filled with water (e.g. wastewater treatment plant effluent) and then heated up to operating temperature. After this at least 10 % of the digester contents should be added as digested sludge from a well operating digester and an increasing raw sludge input should be started slowly. If the feeding of seeding digested sludge is too expensive then the digester can also be started up in that raw sludge is added to the digester once the operating temperature has been reached and with this the mixing plant is operated continuously. In this case the complete start up time, in comparison with the above operating method, is increased only insignificantly (~ 6 - 12 weeks).

Should the pH value fall below 6.8 during commissioning, charging is to be reduced and, if required, measures for neutralisation carried out.

The normal operation of sludge digestion plants is as a rule without problem. Prerequisites for this are a sufficient dimensioning and equipping as well as the observation of various operational rules and, above all, technical safety aspects.

The raw sludge should as far as possible be fed for seeding and for preheating, via the mixing unit to the digester over 24 hours. The mixing together of raw sludge and digested sludge is essential prerequisite for a stable digestion process.

Floating solids, foam and bottom deposits lead to disruption of the digestion process and must therefore be prevented through structural arrangements and operational measures. To these belong the removal of floating solids, the combating of the formation of foam and the prevention of the entry of foam into the gas pipelines, e.g. through foam precipitation, as well as the removal of sand during normal operation.

The operation of the digestion is relatively simple to monitor. To be recorded and controlled are quantity, *DR* content, *oDR* content and, if required, the organic acids of the raw and digested sludge as well as pH value, quantity of digester gas, gas composition and the temperature of the various sludge flows. The necessary measuring facilities are to be installed for this.

Additionally further measurements such as, for example, measurement of filling level, CH_4-/CO_2 analyses or determination of sludge density can be carried out. This is at least worth recommending if the charging of the digester takes place quasi continuously or an increased CO fermentation is planned.

Closed and heated digesters can also be used for digestion of faecal sludge from cess pits and septic tanks or from other organic wastes added, e.g. also to increase the gas yield. Appropriate measures are – so far as they are not already covered through the plant approval – are to be agreed with the supervisory authorities. Such types of co-substrate must be sufficiently pretreated before they are fed directly to the digester or following mixing with the raw sludge.

Disruptions to the digestion process can be recognised in the reduction of the gas production, in the change of the CO_2-component in the digester gas, in the increase of the content of organic acids in the digested sludge, in the fall of the pH value and in the change of the alkalinity. Experienced operating staff can detect disruption of the digestion process in the change to the odour of the digested sludge.

Cause for this is frequently an overloading of the digester with raw sludge. In this case, as a rule, input is to be reduced so far as measures for the intensification of raw sludge seeding and for better thorough mixing are not sufficient. Furthermore, serious changes of the operating temperature, this means an increase/decrease of the digester temperature by more than 1 °C in less than 24 hours, can disrupt the digestion process. The causes for a foaming in the digester are often to be traced back to detergents or to a massive development of thread forming bacteria but are, however, in part not always to be explained satisfactorily. In the case of detergents as causers of foam the symptom can be combatted through the addition of anti-foaming agents.

Poisons or pollutants inhibit the digestion process more severely than the processes of wastewater treatment. Increased heavy metal concentrations can considerably reduce the activity of methane bacteria and thus reduce the production of biogas. In addition, chlorinated hydrocarbons, cyanides, phenols as well as herbicides and insecticides have unfavourable effects.

Should it come, despite all countermeasures, to a complete breakdown of the digestion process then the digester – as described in the section "Commissioning" – should be restarted. An emptying of the digester should be avoided due to the very high operational expense associated with this. Repair work on pipelines or fittings can also be carried out by special diving firms. When possible digesters are to be operated as long as possible and emptied at intervals of 20 years or more. With digestion of bio-P sludge operating problems can occur with deposits of magnesium ammonium phosphate (MAP) The encrustation problem can be met using suitable anti-encrustation agents.

So long as operational instructions and other safety regulations are observed digesters represent no special safety risk. Explosion, suffocation or poisoning hazards due to the medium digester gas can be extensively excluded or avoided already in the planning stage with the observance of safety regulations. All other imaginable hazardous situations in normal and repair operation are to be covered by operating instructions with whose contents operating personnel are to be familiarised through instruction at regular intervals.

Note: For the evaluation of the digester gas a separate Advisory Leaflet ATV-DVWK-M 363 „Herkunft, Aufbereitung und Verwertung von Biogasen [Origin, Processing and Utilisation of Biogas]" (Not yet available in English) (ATV-DVWK 2002a) is available.

4.3 Dual Biological Stabilisation

The "dual sewage sludge stabilisation" is a process chain combined from two different biological process variants of sewage sludge treatment, with which the specific advantages of the respective sub-process are combined together optimally. Through the combination of processes a reduction of the investment and operating costs, an improvement of the energy balance and a qualitative increase of the properties of the stabilised sewage sludge is sought.

Dual stabilisation consists mainly of the coupling of an aerobic, preferably aerobic-thermophilic stage with a downstream anaerobic, preferably anaerobic-mesophilic digestion stage.

In the upstream aerobic-thermophilic reaction stage a heating up of the raw sludge to be stabilised to more than 50 °C is achieved through automatic exothermal metabolic processes. Through this, on one hand, a pre-pasteurisation of the material is enabled and, on the other, a chemical-physical modification of the organic content substance takes place, which offers improved reaction conditions for the subsequent anaerobic biocoenosis.

Other combinations of processes, which are presented in literature as diverse combination possibilities, apart from the combination of thermophilic anaerobic pre-stage and mesophilic anaerobic second stage, have found no broad entry in practice.

Dual sewage sludge stabilisation can be successfully employed for the purposes given below:

- disinfection of the sewage sludge,
- relief of existing sewage sludge digestion plants,

- reduction of investment costs with the establishment of sewage sludge stabilisation plants.

The specific overall digester gas production rate can be increased with the operation of a dual stabilisation.

In the currently applicable [German] sewage sludge ordinance the disinfection of sewage sludge is not promoted as binding process step for the application of sewage sludge to certain agriculturally used areas. It does, however, represent a measure for increasing quality with the utilisation of sewage sludge and is evaluated positively in the area of agricultural customers and users. Current efforts towards revision by the EU demand increased disinfection measures.

The diversely employed sewage sludge digestion effects no disinfection of the raw sludge so that for this area of application the dual sludge stabilisation represents a sensible process supplement as, with its application, an epidemic-hygienic end-product is created.

In addition to the effect of disinfection a controllable pre- or partial degradation of the organic sewage sludge content substances is effected through the aerobic-thermophilic stage according to the respective constraints.

As the aerobic-thermophilic stabilisation has considerably shorter reaction times (ca. 1/4) compared with the anaerobic digestion, the necessary investment costs for their installation in appropriate scope in comparison with digestion are more favourable. For this reason in many cases a cost effective retrofitting using a thermophilic pre-stage offers itself for overloaded digestion plants of smaller and more medium sizes.

If with such cases of application the disinfection is not taken into account as process goal then the process chain can be installed without facilities for a forced heating.

The investment costs of biological sewage sludge stabilisation can possibly be reduced through the employment of an aerobic-thermophilic pre-stage. Analogous to the retrofitting of already existing digestion plants these facts can be used also with new establishment of stabilisation systems.

Here, however, thought is to be given that for small and medium connection capacities possibly the exclusive aerobic-thermophilic stabilisation or anaerobic digestion stages in a ready-made structural form can represent a more favourable overall solution.

5 Hygienic Aspects

German legislation in the first Sewage Sludge Ordinance has from 01 January 1987 limited the application of treated sewage sludge on pasture-land and areas under crop cultivation in that this material must be epidemic-hygienically safe.

For this reason the previous ATV/VKS Working Group 3.2.2 presented three reports on the subject field “Disinfection of sewage sludge” in which the processes suitable for the disinfection of sewage sludge and their control are described in detail under practice-relevant conditions (ATV 1986, 1988, 1988a).

For agricultural utilisation according to current legal specifications a hygienisation is not necessary. The drafts of the EU (European Commission 2000) for the amendment of the Sewage Sludge Directive, however, prefer a hygienisation depending on the area of application so that, presumably, these processes in future could gain in significance.

For more extensive information attention is also drawn to the Advisory Leaflet ATV-M 365 „Hygiene bei der biologischen Abfallbehandlung – Hinweise zu baulichen und organisatorischen Maßnahmen sowie zum Arbeitsschutz [Hygiene with the Biological Treatment of Waste – Notes on Structural and Organisational Measures as well as Protection of Labour]“ (Not yet available in English) (ATV 1999a).

6 Areas of Application

With the biological stabilisation process, irrespective of decision specifications which result from the overall objective of the respective process chain of the sewage sludge treatment, there result areas of application to be recommended dependent on the capacity of the respective wastewater treatment plant.

In Diag. 4 are presented appropriate areas of application for the most important variants of biological sewage sludge stabilisation.

As such recommendations for employment can only be the result of subjective evaluation yardsticks of individual specialists or specialist groups, here there result differences due to the different weighting of ecological, economical and technical influencing factors.

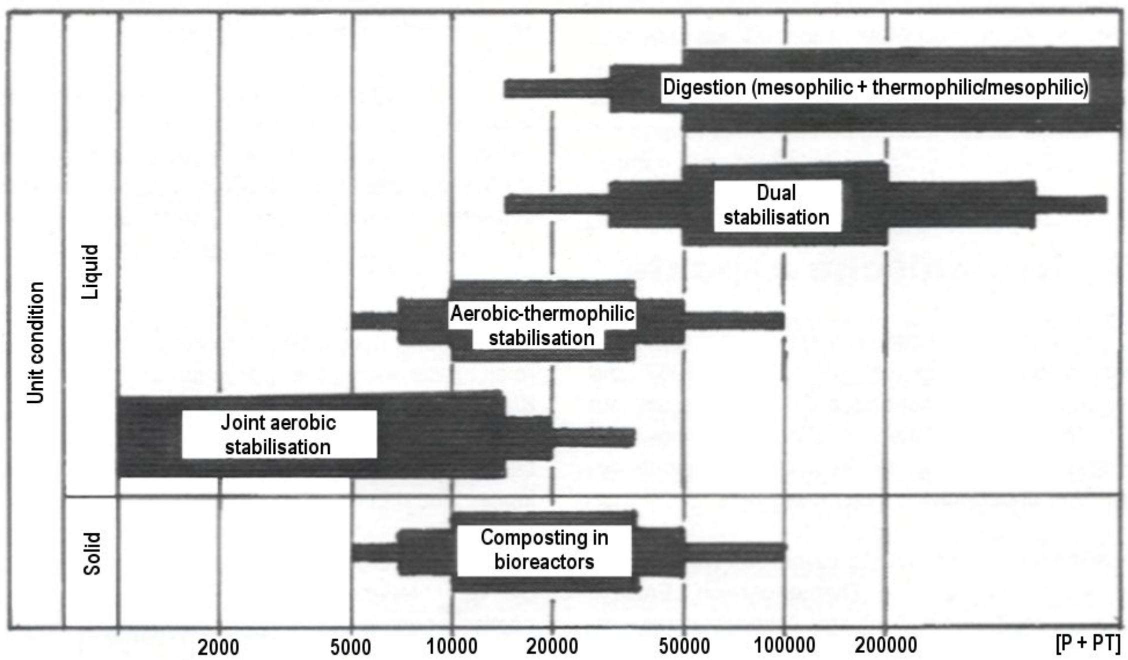
What is decisive is that, with the classification of processes presented here, one cannot just be concerned with an obligatory and "computable" general system, but rather that dynamic displacements are to be taken into account with the classification of areas of application, which are usually created through amended legislative targets set in the fields of wastewater treatment as well as the utilisation or disposal of the sewage sludge.

Thus, for example, the demand for nitrogen removal with the treatment of wastewater has brought with it that the process of joint aerobic stabilisation again finds an expanded application.

Correspondingly counter to this is the trend with processes with disinfecting effect (aerobic-thermophilic and dual stabilisation) as, through some laws or decrees, the agricultural utilisation of sewage sludge is limited and has been prohibited with pastureland and on areas under crop cultivation in Germany.

According to the current status of technical discussion it should, however, be largely undisputed that, for the majority of specialists, with wastewater treatment plant capacities of less than 10,000 P + PT the "joint aerobic stabilisation" and with wastewater treatment plant with more than 50,000 P + PT aerobic digestion also with aerobic-thermophilic pre-stage, or dual process combinations are the processes of choice.

Only in the area of the medium-sized wastewater treatment plants between ca. 10,000 to 50,000 P + PT is a differentiated project-related process comparison to be particularly recommended, taking into consideration respective stabilisation and disposal goals with the inclusion of the complete process chain of wastewater treatment and sewage sludge treatment.



Diag 4: Recommended areas of application for biological sewage sludge stabilisation processes

Composting in bioreactors which ultimately represents a sewage stabilisation in solid aggregate state cannot be combined sensibly with an anaerobic digestion stage and is to be viewed as process alternative for smaller and more medium-sized plants.

7 Bibliography

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